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..eather-Monitoring Instrumentation for Plant Disease Management Programs and Epidemiological Studies

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W. E. MacHardy and J. Sondej

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ABSTRACT

The construction and operation of battery-operated field instrumentation for plant disease management programs and epidemiological studies are described and illustrated. The major components are a digital rain gauge and leaf wetness indicator coupled to pen arms added to a hygrothermograph which also monitors and records temperature and relative humidity. The instrumentation has several characteristics considered essential for the programs being developed in New Hampshire: low-cost, low-maintenance, simplified design and technology, durability, reliability, and flexibility (adaptable to orchard and field crop conditions). Temperature (°F or °C), relative humidity, duration (hrs) of leaf wetness, rainfall (0.25 mm), and rain-intensity (occurrence of each 0.25 mm of rain) are monitored and recorded. In addition, the instrumentation can be wired to activate a spore trap or other device during periods of leaf wetness. An important feature is a visual record of the temperature, relative humidity, duration of leaf wetness, and rain-intensity and distribution on one chart. This allows these weather variables to be readily examined and assessed in the field either individually or as they interrelate.

KEY WORDS: Integrated Pest Management, Disease Management, Leaf Wetness Indicator, Field Instrumentation, Weather Variables.

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Weather-Monitoring Instrumentation for Plant Disease Management Programs and Epidemiological Studies

by
W. E. MacHardy and J. Sondej*

INTRODUCTION

The instrumentation described in this bulletin has been developed to sense and record weather data required for epidemiological studies and disease management programs of apples and potatoes. However, the adaptability of this instrumentation and the data it provides allow it to be used with a wide range of crops, diseases, and management programs. The instrumentation has several features considered essential for the programs being developed: low-cost, low-maintenance, limited-servicing, simplified design and technology, easy-calibration, battery-operation, durability, reliability, and flexibility (adaptability to orchard and field crop conditions). The following environmental variables can be monitored and recorded:

1. temperature (°F or °C)
2. relative humidity (%)
3. leaf wetness (hrs.)
4. rainfall (0.25 mm)
5. rain intensity (occurrence of each 0.25 mm of rain)

An important feature is a visual record of the temperature, relative humidity, duration of leaf wetness, and rainfall intensity aligned on one chart. This allows a person to immediately examine, compare, and assess these variables in the field, either individually or as they interrelate.

Two instrumentation designs are described. Each design records the same weather data (Fig. 1), and each utilizes a standard two-pen arm hygrothermograph as the main component. In addition, each design includes a digital rain gauge (a_1, a_2, Fig. 2) and a device for indicating the hours of leaf surface wetness (b, Fig. 2), both of which are linked electronically to pen arms on the hygrothermograph (c, Fig. 2). The major distinction between the two designs is that one requires modification of a hygrothermograph to accommodate two additional pen arms (Fig. 1-A) while the other requires only one

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additional pen arm (Fig. 1-B). The four-pen arm design has the advantage of being adaptable to almost any hygrothermograph; however, one disadvantage is that more time and labor are required for its construction compared to the three-pen arm design. The three-pen arm design has a major disadvantage in that only the hygrothermograph pictured, or one of similar construction, can be used, since it must be constructed to accommodate the solenoid attachment shown in Fig. 20. An advantage of this design is that it is easier to construct since only one additional pen arm assembly is required.

The step-by-step instructions for construction of the two designs are very specific, but they apply only to the hygrothermograph model, rain gauge, and materials listed. The hygrothermograph model is one we have found to be reliable and durable, but several makes are available that can be substituted, especially when constructing the four-pen arm design. The digital rain gauge was selected because it was relatively inexpensive, durable, and accurate for our purposes; but again, similar instruments are available that may be substituted. The materials listed were selected because they were readily available at local hardware and electrical supply stores. It is not likely that identical materials will be available in other locations, and even different makes of hygrothermograph and rain gauge may be selected. If so, then the detailed instructions and materials specified here will serve primarily as a useful framework from which modifications will be necessary for constructing this instrumentation.

PURPOSE

The purpose of this bulletin is to provide written and illustrated instructions for constructing and calibrating this instrumentation and an explanation of its operation.

BRIEF DESCRIPTION OF FIELD OPERATION

The major components are a digital rain gauge and a leaf wetness indicator coupled to pen arms on a hygrothermograph which also monitors and records temperature and relative humidity (see cover). The hygrothermograph must be placed within an instrumentation shelter to shield the sensing elements from direct sunlight and precipitation. The rain gauge must be located in an open area free from any obstruction that would hinder rain from collecting in the rain gauge. The leaf wetness indicator should be placed within the canopy of the crop, preferably in a location that would allow the longest drying period following precipitation or dew.

The hygrothermograph sensing units monitor and record temperature and relative humidity continuously. When it rains, precipitation collects in the rain gauge and every 0.25 mm of rain is recorded on a counter (a_2, Fig. 2) and on the hygrothermograph chart (rain-intensity line, Fig. 1). The counter indicates the amount of rain that has fallen while the rainfall intensity traced on the chart provides a record of the distribution of rain with time. The length of time (hrs) the leaves remain wet is measured indirectly by the leaf wetness indicator, a string device that simulates leaf wetness. Precipitation increases tension on the string mechanism, causing an electric circuit to be completed which results in a momentary drop in the leaf wetness pen arm every 5 to 7 minutes the string device remains activated. The pattern traced on the chart during wetness is a thick line which is solid during periods of heavy rainfall (Fig. 1). Tension on the sensing mechanism can be adjusted to include condensation (dew) in addition to precipitation (rain).

DESCRIPTION OF MAIN COMPONENTS

Hygrothermograph

The hygrothermograph is a portable instrument designed to furnish accurate, continuous records of temperature and relative humidity which are traced by separate pen arms onto a 7-day rectangular chart marked-off at two-hour intervals. The chart is mounted on a cylinder which revolves once in 176 hrs (weekly). A spring-wound clock mechanism drives the cylinder. In the model pictured (Fig. 1), the temperature-response unit consists of a Bourdon tube mounted at the right front of the instrument and its associated lever system. The humidity-sensitive unit consists of a hair element mounted at the right rear of the instrument with the associated lever system. The instruction manual should be consulted for further details on operation, maintenance, and repair.

Felt tip pens that snap onto the pen arms should be used in place of the standard tips with ink wells that must be continually filled with ink. The quick response of the leaf wetness indicator and rainfall-intensity pen arms will cause the ink in the standard tips to spatter. Also, the standard tips tend to clog and run dry if not attended to regularly, whereas the felt tip pens require no servicing during the growing season.

Calibrating the hygrothermograph. It is advisable to check the calibration of the temperature and relative humidity units each time the chart is replaced. Do not remove the hygrothermograph from the shelter, and make sure there is no direct sunlight shining on the sensing elements.

Temperature. Use a thermometer accurate to 1.0 C. Wipe the temperature-sensing element with a clean, soft cloth. Support the thermometer tip near the temperature sensing element and note the temperature after the thermometer has come to rest. Then adjust the temperature pen arm apparatus according to directions supplied with the hygrothermograph.

Relative humidity. Use a sling psychrometer or other instrument capable of measuring relative humidity with 2.0% or better accuracy. Make sure the humidity is measured within the shelter or away from direct exposure to sunlight. Adjust the humidity pen arm apparatus according to directions supplied with the hygrothermograph.

Digital Rain Gauge Assembly

The digital rain gauge assembly consists of the following main components: rain collector (a_1, Fig. 2), tipping bucket (Fig 3), digital counter (a_2, Fig. 2), and the rain-intensity relay and pen arm (Fig. 1). The rain gauge is wired to record each 0.25 mm of rainfall on the digital counter and on the hygrothermograph chart. The rain gauge was selected because of its accuracy (0.25 mm $\pm$ 5%) and low cost. Rain gauges with greater accuracy are available, but they are also considerably more expensive.

Operation. A tipping-bucket is located in the base of the rain collector (Fig. 3). The bucket is actually two buckets joined together. One bucket is always aligned with the orifice in the rain collector. When 10 cc of water (equivalent to 0.25 mm of rainfall) are passed from the rain collector to the tipping-bucket, the bucket tips causing the water to drain while at the same time aligning the second bucket with the orifice.

A magnetic bead is attached to the center of the tipping-bucket, and is located adjacent to a magneswitch (b, Fig. 3). When the bucket tips, the magnetic bead swings along the magneswitch, causing two metallic strips in the switch to be momentarily drawn together. At this time the circuitry that connects the switch to the digital counter and the rainfall-intensity pen arm is completed. The digital counter is advanced one unit and the pen arm is pulled downward and then quickly returned to its resting position as the magnetic bead continues its swing and the metallic strips are again separated. The power required to trip the digital counter and the pen arm relay is provided by two 9 V transistor batteries housed in the digital counter.

The digital counter provides a direct reading of the amount of rainfall that has occurred within a given period, while the rainfall-intensity pen arm traces the distribution and intensity of rain on the hygrothermograph chart over the same period. With most rain peri-

ods, the tracing on the chart will be too congested to allow an accurate determination of the amount of rain that has fallen (note the extended solid rain-intensity line in Fig. 1-A).

The rain collector should be inspected periodically to make sure that no debris has collected in the orifice. It is also recommended that the collector and the tipping-bucket be washed periodically with a mild detergent to maintain a smooth, clean surface for the rain to drain properly. Dirty and greasy surfaces will affect the accuracy.

Leaf Wetness Indicator

The leaf wetness indicator (LWI) apparatus does not measure leaf surface wetness directly; rather, it provides an indication of the time interval when leaf surfaces are wet through the wetting and drying of a sensing element. The LWI is not attached directly to the hygrothermograph, and this allows considerable flexibility in locating the sensing element within the canopy or cover of a wide range of crops. Thus, it can be placed within a field of wheat or the canopy of an apple tree (see cover) or a potato plant. The only major requirement is that no plant parts, soil, or other objects contact the sensing element. The LWI is comprised of the following components:

1. Wetness sensing element (a, Fig. 4)
2. Sensor relay (b, Fig. 4)
3. Sensing element tension-adjustor (c, Fig. 4)
4. LWI housing (d, Fig. 4)
5. Sensor indicator assembly (e, f, Fig. 4)
6. Unijunction assembly (circuit board and components; b, Fig. 16)
7. Unijunction accelerator switch (a, Fig. 16)
8. Leaf wetness pen arm and pen arm relay (Fig. 1)

Sensing element. The wetness sensing element is a length of cotton chalk line with a solderless ring tongue lug crimped to each end for attachment to the sensor relay and the sensing element tension adjustor. Cotton chalk line is used by carpenters to mark lines on wood surfaces. It was selected because it is responsive to wetting and drying but does not need to be degreased. Other leaf wetness indicators have used degreased hemp. This material works, but hemp is hard to find and even harder to degrease since extraction apparatus is necessary.

Operation of Sensing Element. The sensing element constricts when it becomes moistened by rain or dew, causing the contact plate in the sensor relay to be pulled toward copper contact C_1 (Fig. 5-A). If the contact plate (C_p) and contact C_1 do make contact (Fig. 5-B), then the electrical circuitry to the unijunction and LWI relay and pen arm is 'closed'. The unijunction circuitry is now activated and the LWI

pen arm should be recording 'wet' within 7 to 10 minutes. The contact plate in the LWI relay will return to the 'dry' position (Fig. 5-A) when the sensing element has dried and slackened sufficiently.

Sensor indicator assembly. This assembly consists of the sensor indicator switch and an LED (Light Emitting Diode) (Fig. 4). It provides a means to quickly check the electric circuitry connecting the sensor relay, unijunction assembly, and the LWI pen arm relay to see if it is 'open' or 'closed'. The sensor indicator switch (f, Fig. 4) is pressed (1) when conducting an operational check of the LWI circuitry to make sure it is functioning properly, (2) when calibrating the LWI, or (3) when it is necessary to know if the LWI sensor relay is in the 'wet' or 'dry' mode. If the sensor indicator switch is pressed and the LED glows, then the circuitry is 'closed'. This means that the unijunction assembly is receiving an electric current from the battery and the LWI pen arm should be reading 'wet'. Remember that the unijunction assembly must be activated for 7 to 10 minutes before the first response of the LWI pen arm will occur. If the switch is pressed and the LED does not glow, then the circuitry is 'open' and the LWI pen arm should be recording 'dry'.

Unijunction accelerator switch. The unijunction accelerator switch (Fig. 16) hastens the time required for the unijunction assembly to discharge and activate the LWI pen arm relay. It is a 'momentary on' switch, which means that it will only be 'on' when it is pushed and held in the 'on' position. This feature is desirable since it eliminates the possibility of forgetting to return the switch to the 'off' position, which would result in a draining of the battery and a false tracing of wetness on the chart. The purpose of the unijunction accelerator switch is to reduce the time required for the unijunction assembly to 'fire' the LWI pen arm from about 8 minutes to only a few seconds. This will save a considerable amount of time when conducting an operational check of the LWI circuitry.

Unijunction transistor oscillator assembly (unijunction assembly, Figs. 16, 17). The unijunction assembly provides a drive circuit for activating the LWI pen arm relay. Its extremely low current consumption and inherent pulse-type output several minutes apart are what make possible the use of only one 12 V lantern battery for a period of several months or longer.

Operation of Unijunction Assembly (Fig. 6). The operation of the unijunction circuitry revolves around the slow-charging and quick-discharging of a 500uF electrolytic capacitor (C_1). A 200 ohm resistor (R_1) provides a small current for charging C_1, which takes several minutes. In this charging state, it is as if the connection to the emitter (E) of the transistor (T_1) were not present. Then, when the voltage across C_1 reaches approximately 8 V, the emitter to base 2 (B_2) junction of the transistor breaks down to nearly zero resistance

and quickly discharges the capacitor (C_1) through the relay coil (K_1). The 'surge' of current passes from K_1 to a solenoid in the LWI pen arm relay, causing the relay to close. When the relay closes, the pen arm is forced downward. The pen arm returns immediately to its original position, since the increased electric current is only momentary. With C_1 now discharged, the transistor (due to its inherent nature) reverts to its original non-conductive state and the capacitor starts charging again. This procedure repeats over a 7 to 10 minute period as long as the electric circuitry to the 12 V battery is connected, i.e. as long as the sensing element is causing the LWI sensor relay to remain in the 'wet' position.

Instrument Shelter

A shelter is necessary to house the hygrothermograph, rain gauge digital counter, and other items. The model pictured (see cover) is the U.S.A. Weather Bureau Instrument Shelter, but other suitable commercial shelters are available, and home-made shelters with similar features are also acceptable and will likely be much less expensive. The shelter should be white, and should have louvered sides or other allowances for air exchange to insure accurate ambient temperature and relative humidity readings.

CONSTRUCTING THE 4-PEN ARM DESIGN

Preparing the LWI and Rain-intensity Pen Arm Relays

Materials

(1) 12 VDC relay, KRP11DG (AMF/Potter & Brumfield, Princeton, Indiana 47671, U.S.A.)
(1) 6 V 50-60 HZ relay, KRP11AG (AMF/Potter & Brumfield)

Instructions (refer to Fig. 7)

1. Remove plastic hex nut and four screws from plastic relay housing. Discard screws and plastic case.
2. Cut the eight wires leading to contacts and coil (a)
3. Remove and discard the fibreboard mount (b)
4. Temporarily remove retaining spring on back of relay. Remove metal plate with attached copper contact strips. Bore through the two rivets securing the contact strips to plate. Discard the contact strips.
5. Replace metal plate and retaining spring (c)

Constructing the LWI and Rain-intensity Pen Arms

Materials

(1) 30 cm flat strip of 0.5 mm x 6.0 mm brass stock (obtainable at hobby shops)
(1) 30 cm flat strip of 1.0 x 6.0 mm brass stock
(2) Universal Series 39 disposable snap-on felt tip pens (Graphic Controls Corporation, 2 Springdale Road, Cherry Hill, New Jersey 08003, U.S.A.)
(1) length of 18 gauge solid core copper wire
(4) screws

Instructions (refer to Fig. 8)

1. Fashioning the pen arms
   a. Cut an 8.5 cm length of the 0.5 mm x 6.0 mm brass stock to fashion into a pen arm for the 12 V relay.
   b. Cut a 9.5 cm length of the 0.5 mm x 6.0 mm brass stock to fashion a pen arm for the 6 V relay.
   c. Prepare each pen arm as follows:
      (1) From one end of the brass stock, *twist* a 1.5 cm length 90 degrees (a).
      (2) From the other end, use a file to narrow a 2.0 cm length to 3.0 mm wide (b).
      (3) Crease the center of the remaining stock slightly to add rigidity to the pen arm.
2. Attaching the pen arms to the relays (c).
   a. Drill two 2 mm holes, spaced 4 mm apart, through the twisted 1.5 cm end of the brass stock.
   b. Drill two corresponding holes in the metal plate of the relay.
   c. Secure the pen arm onto the relay plate using two 2.0 mm lengths of the 18 gauge solid core wire.
   d. Rivet the pen arm in position by flattening the wire lengths into the holes with a hammer.
3. Preparing the gap-adjustor bracket (repeat for each relay)
   a. Cut a 7.5 cm length of the 1.0 x 6.0 mm brass stock (d).
   b. Measure 4.0 mm from each end of the stock and mark.
   c. Drill a 2.0 mm hole at one mark and a 3.0 mm hole at the other mark.
   d. From one end of the stock, mark-off 2.5 cm and 5.0 cm. At each mark, *bend* the stock 90 degrees (e, f).
   e. The adjustor is attached to the relay by threading a screw through the 3.0 mm hole to the bottom of the relay (e).

f. Thread a screw through the 2.0 mm hole (f). This screw is used for adjusting the gap between the relay plate and the coil. The proper gap is critical to the 'firing' of the relay.
   (1) Adjust the gap on the 12 V relay to 0.559 mm, using a feeler gauge.
   (2) Adjust the gap on the 6 V relay to 0.254 mm.
g. Attach felt tip pens to the pen arm (g).

Constructing the Plexiglass Stage and Attaching the Pen Arm Relays

Materials

(1) 3.0 mm thick plexiglass stock 22 x 15 cm (for sides and the relay plate)
(1) 6.0 mm thick plexiglass stock 8 x 15 cm (for the base and top of the stage)
(2) brass bolts
(1) 25 ml bottle of ethylene dichloride
(2) brass screws

Instructions (Refer to Figs. 9-11)

1. Refer to Fig. 10 for dimensions of plexiglass sections and location of drill holes and grooves.
   a. Cut each section.
   b. Drill *all* required holes.
   c. Saw a groove in each side piece for attachment of the LWI relay plate
2. Place the plexiglass base plate lengthwise 6.0 cm from center of the guidepost and 3.3 cm from the back edge of the hygrothermograph base plate (Fig. 9).
   a. Use a scribe to etch the position of the plexiglass base plate.
   b. Keep the plexiglass base plate in place, and use as a template to mark the position of the holes to be drilled in the base of the hygrothermograph (Fig. 9).
      (1) Drill the two outer holes with a 4.0 mm drill bit, and use a tap corresponding to the drill bit size to thread the holes.
      (2) Drill the center hole with a 6.0 mm bit.
3. Attach the 12 V and 6 V relays to the stage (Fig. 11).
   a. Drill two 4.0 mm holes in stage for attaching the relays (Fig. 10). Screw the 12 V relay to the top section of the stage. Screw the 6 V relay to the LWI relay plate.

4. Bond the plexiglass sections using ethylene dichloride.
   a. Begin assembly with plexiglass base secured to the hygrothermograph.
   b. With an eyedropper, coat the bonding surfaces with a thin film of ethylene dichloride. Bonding will occur within minutes.
   c. Bond sides to base.
   d. Bond top to sides.
   e. Coat the edges of the LWI relay plate and the grooves of the stage with ethylene dichloride, then slide the relay plate into the grooves and align so that the plate extends 25 mm beyond the *front* edge of the stage (Fig. 11).

Constructing the Leaf Wetness Indicator (LWI)
Modifying the Sensor Relay

Materials

(1) 12 VDC 4 PDT relay, rated 3A at 125 VAC (Radio Shack, Tandy Corp., Forth Worth, Texas 76102, U.S.A.; Model #275-214)
(1) 10 cm length of thin wire (connects to relay plate, for hook attachment)
(1) 10 cm length of thin wire (to attach hook to wire cemented to relay plate)
(1) 5 cm length of 17 gauge wire (to fashion a hook)
(1) tube of silicone cement

Instructions (refer to Figs. 12, 13)

1. Temporarily remove plastic case from relay.
2. Remove the solenoid by drilling through the rivet attaching the solenoid to the relay housing.
3. Cement a thin wire to the contact plate, and pass the wire through the hole in the relay housing left from the removal of the rivet (a, Fig. 12).
   NOTE: Make sure the wire is attached in such a way that it will not short-out the contacts.
4. Cut a slit in the plastic relay cover so that the wire may pass through the slit. This will allow the cover to be removed without disturbing the wire (b, Fig. 12).
5. Fashion a hook from a 2 cm length of 17 gauge wire (a, Fig. 13) and attach to the end of the wire cemented to the contact plate. Fasten the hook to the wire from the relay by winding a 10 cm length of wire around the hook and relay wire (b, Fig. 13). The hook will later be attached to one end of the sensor element.

6. Return the plastic cover to the relay.
7. See below for attaching the relay to the sensor housing.

Wiring the Relay

Materials

(1) PVC test cap
(1) spool of 16 gauge stranded, two-conductor speaker wire

Instructions (refer to Figs. 13, 14)

1. Cut slits in the PVC test cap so that they correspond to prongs on the relay (c, Fig. 13)
2. Insert the relay prongs through the slits in the test cap.
3. Cut the two-conductor speaker wire to a length long enough to extend from the sensor relay through the PVC 'T' (see Fig. 14).
   a. Sever the *positive* (copper) lead and connect the cut ends to the relay as follows:
      (1) Solder one cut end to the 2nd position contact.
      (2) Solder the other cut end to the 3rd position (contact plate with copper strips).
      (3) Apply silicone cement to the soldered connections.

Attaching the Sensor Relay to the Sensor PVC Housing

Materials

(1) PVC adapter with plug
(1) PVC elbow (90 degrees)
NOTE: Use 3.8 mm diameter stock for all polyvinyl chloride (PVC) components.

Instructions (refer to Fig. 15)

1. Drill a 6.0 mm hole in the rim of the sensor elbow to correspond with a, Fig. 15.
2. Secure the sensor relay against the PVC test cap.
   a. Add silicone cement to the test cap/relay interface.
   b. Bend the unwired prongs firmly against the test cap.

NOTE: Make sure all electrical wiring to the sensor relay is completed *before* the relay is secured to the elbow. If a spore trap or other instrument is to be activated during periods of leaf wetness, it should be wired to the sensor relay before the relay is cemented to the elbow (see section, 'Attaching a spore trap to the instrumentation').

3. Extend the hooked wire through the 6.0 mm drilled hole, and then carefully seat the sensor relay/test cap in the elbow.

Apply PVC cement to the test cap and lip inside the elbow before seating. Make sure the hooked wire can move freely in the hole.

4. Saw a slit in the rim of the adapter, extending perpendicularly from the edge to the flange. This slit allows the adapter and cap to be removed without disturbing the wire hook (b). Add silicone grease to the rim of the elbow and adapter, then screw the PVC plug firmly into the adapter. Align the slit with the hooked wire, and seat the adapter into the elbow.

Preparing the Sensing Element Tension-adjustor Assembly

Materials

(1) PVC adapter with plug
(1) PVC elbow (90 degrees)
(1) 10 cm length of polyester string
(1) 6.0 mm diameter by 10 cm length screw-eye bolt
(1) dial knob (with set screw) that will accept a 6 mm shaft
(1) wing nut (for screw-eye bolt)

Instructions (refer to Fig. 15)

1. Drill a 6.0 mm hole through the PVC elbow (a). The hole must align with the 6.0 mm hole drilled into the sensor relay elbow.
2. Drill a 1.0 mm hole through the mid-point of the screw-eye bolt.
3. Drill 6.0 mm holes through both sides of the PVC elbow (c). The eye-bolt will be threaded through these two holes, so they should be drilled in a direct line through the center of the elbow. When the eye-bolt is threaded, its center should be perpendicular to the 6.0 mm hole drilled in step 1 (see c, Fig. 4).
4. Thread the screw-eye bolt into the PVC elbow.
5. Remove the eye of the bolt by sawing, and replace with a dial knob.
6. Screw the wing nut onto the threaded end of the eye-bolt.
7. Attach a short length of polyester string to the 1.0 mm hole in the eye-bolt, and pass the string through the 6.0 mm hole in the front of the elbow. This string will be used later for attaching the tension-adjustor assembly to the sensor element.

Installing the Sensor-indicator Light-Emitting Diode (LED) and Switch

Materials

(1) LED lamp T1 ¾ (Radio Shack, Model 276-041)
(1) momentary-on pushbutton switch, SPST (Radio Shack,

model 275-618)
(1) 680 ohm resistor
(2) 20 cm length of 16 gauge stranded, single-conductor wire
(1) PVC 'T'

Instructions (refer to Figs. 14, 15)

1. Drill a 3.0 mm hole in the top of the PVC 'T' (d, Fig. 15).
   a. Extend one of the resistor leads up through the hole and solder to the *anode* of the LED (a, Fig. 14).
   b. Extend one end of a 20 cm length of 16 gauge wire up through the hole and solder to the *cathode* of the LED (b, Fig. 14).
   c. Lower the LED into the hole and cement into place.
2. Drill a 13 mm hole on the side of the PVC 'T' (e, Fig. 15).
   a. Extend the second lead of the resistor through the hole and solder to one of the contacts on the sensor indicator switch (c, Fig. 14).
   b. Extend one end of the *second* length of 16 gauge wire out through the hole and solder to the remaining contact on the sensor indicator switch (d, Fig. 14).
   c. Insert the switch into the hole and cement into place.

Assembling the Sensor PVC Housing

Materials

(2) 9 cm length of PVC tubing
(1) length of PVC tubing (see below for length)

Instructions (refer to Fig. 15)

1. Saw two 9 cm lengths of PVC tubing.
2. Assemble the two lengths of tubing, the two elbows, and the PVC 'T'.
3. Adjust the pieces so that the distance between the two 6.0 mm holes in the elbows is approximately 31 cm.
4. Cement the pieces together with PVC cement.

Preparing the Sensing Element

Materials

(1) spool of cotton chalk line
(2) solderless ring tongue lug

Instructions (refer to Fig. 15)

1. Cut a 29 cm length of cotton line.
2. Place a lug on each end and crimp firmly into place.

3. Check to make sure the length is correct. The string should be stretched when it is placed between the elbows of the sensor housing.

Conditioning the Sensing Element

The wetness sensing element should be 'conditioned' before it is attached to the LWI assembly so that it will respond properly to wetting and drying. Always handle the sensing element by holding the lugs. Touching the cotton line will leave grease on it which may lessen the response of the element to wetting. It is suggested that two or three spare elements be 'conditioned' for immediate replacement in the event of vandalism or some other catastrophe that makes the sensing element inoperable. The 'conditioning' may be accomplished by the following procedure:

1. Hammer two small nails into a board and slip the lugs of the sensing element over the nails. The nails should be spaced so that the sensing element is stretched.
2. Spray the element uniformly with water until it is thoroughly wetted. Use a spray atomizer, aerosal spray can, or other device that provides a mist-type spray.
3. Allow the element to dry.
4. Repeat 4 to 6 times.

The sensing element is now 'conditioned', and can be attached to the LWI assembly.

Attaching the Wetness Sensing Element to the Sensor PVC Housing

1. Attach one lug to the hook extending from the sensor relay housing.
2. Attach the other lug to the polyester string extending from the tension-adjustor housing.
3. If the sensing element is sagging, turn the tension-adjustor knob *clockwise* slowly until the sensing element does not sag.

NOTE: The construction of the LWI sensing unit is now complete. It may be supported on a length of PVC tubing (see cover). The length of tubing will vary depending on placement of the sensing unit in the environment. Several wires should be extending through the PVC 'T'. The connection of these wires is explained below in the section, 'Wiring the LWI sensor, unijunction assembly, and LWI relay'.

Preparing the Unijunction Assembly

Materials

(1) circuit board

(1) 220 ohm resistor, ½ watt, 5% tolerance
(1) 470k ohm resistor, ½ watt, 5% tolerance
(1) electrolytic capacitor, 500 uf 0-25 DC
(1) unijunction transistor ECG6401 (GTE Products Corp., Waltham, Massachusetts 02154)
(2) brass bolts

Instructions (refer to Figs. 6, 16)

1. Solder the electrical components to the circuit board (Fig. 6). *NOTE:* Be careful not to overheat the unijunction transistor when soldering, as it may be damaged by very high temperatures.
2. Drill and tap two holes in the rear of the plexiglass stage and bolt the circuit board to the stage (Fig. 16).

Mounting and Wiring the Unijunction Accelerator Switch

Materials

(1) SPDT momentary spring-return switch, 6A, 125 VAC
(1) 4.7k ohm resistor, ½ watt, 5% tolerance
(2) 10 cm length of 18 gauge single-conductor wire

Instructions (Refer to Figs. 6, 16)

1. Mount the momentary spring-return switch on the plexiglass stage (Fig. 16).
2. Solder one end of a 10 cm length of 18 gauge wire to the positive end of the electrolytic capacitor, and solder the other end to the 4.7k ohm resistor.
3. Solder the resistor to the center pole of the momentary switch (a, Fig. 6).
4. Solder one end of a 10 cm length of 18 gauge wire to the junction of the 220 ohm and 470k ohm resistors (b, Fig. 6), and solder the other end to the (normally open) pole of the switch (c, Fig. 6).

Wiring the Unijunction Assembly to the LWI Pen Arm Relay

Materials

(2) 15 cm length of single-conductor 18 gauge wire

Instructions (refer to Fig. 6)

1. Solder one end of 18 gauge wire to one of the prongs on the 6 V LWI relay, and solder the other end to prong B_2 of the unijunction transistor.

2. Solder one end of 18 gauge wire to the other prong on the 6 V relay, and solder the other end to the negative end of the electrolytic capacitor (C_1).

Wiring the Sensor Relay to the Unijunction Assembly, Sensor-indicator Assembly, and Battery

Materials

(2) length of two-conductor speaker wire (see below for length)
(1) 12 V lantern battery
(6) 'quick-disconnect' wire connectors

Instructions (refer to Fig. 14)

1. The following leads should be extending from the PVC 'T'
   a. Two leads of two-conductor speaker wire (attached to the sensor relay). There may be a third lead if a spore trap is going to be attached to the sensor relay.
   b. Two leads of 16 gauge stranded single-conductor wire (attached to the LED and switch of the sensor indicator assembly).
2. Wire the sensor-indicator LED and switch to the sensor relay
   a. Select one of the speaker wire leads and strip about 15 mm of insulation from the end of each strand.
   b. Solder the copper (positive) strand to the 16 gauge lead attached to the switch (e).
   c. Solder the silver (negative) strand to the 16 gauge lead attached to the LED (f).
3. Cut two lengths of speaker wire long enough to extend through the PVC tubing supporting the sensor unit, along or under the ground, and into the instrument shelter once the apparatus has been installed in the field. Within the shelter, one wire will connect to the 12 V lantern battery and the other wire will connect to the unijunction assembly.
4. Solder 'quick-disconnect' plugs to the ends of the copper and silver strands of each speaker wire lead extending from the PVC 'T' and also to the ends of each strand of the speaker wire that will attach to them. These plugs will allow the sensor unit to be removed and attached, if necessary, without disturbing the remainder of the apparatus.
5. Wire the sensor relay to the unijunction assembly.
   a. Connect one of the long lengths of speaker wire to the speaker wire selected for 2, above.
   b. Insert the other end of this wire through the drilled hole in the hygrothermograph base and plexiglass stage.
   c. Solder the positive (copper) strand to the junction of the

220 ohm and 470k ohm resistors (see Fig. 17).

d. Solder the negative (silver) strand to the negative lead of the electrolytic capacitor (see Fig. 17).

e. Sever the speaker wire about 10 to 20 cm from its entrance into the hygrothermograph, and solder 'quick disconnect' plugs to each of the cut strands. This will allow the hygrothermograph to be detached from the sensor unit without disturbing the apparatus.

6. Wire the sensor relay to the 12 V lantern battery.

a. Connect the second long length of speaker wire to the plugs on the other speaker wire lead extending from the PVC 'T'.

b. The other end of this wire is attached to the battery.

NOTE: This completes the construction and wiring of the LWI apparatus.

Operational Check of the Leaf Wetness Indicator Circuitry and Trouble-shooting

The electrical circuitry connecting the sensor relay, sensor-indicator assembly, unijunction assembly, and the LWI pen arm relay can be checked by the procedure outlined below:

1. Depress the sensor-indicator button.

a. If the LED glows, proceed to step 2.

b. If the LED does not glow, loosen the wing nut and turn the tension-adjustor knob *clockwise* slowly until the LED glows. Proceed to step 2.

(1) If there is continued failure of the LED to glow, this may be due to:

(a) improper wiring: check all wiring and connections

(b) low battery charge

(c) malfunctioning LED

(2) Correct the problem and proceed to step 2.

2. Push and hold the unijunction accelerator switch. In a few seconds, the LWI pen arm should click up and down to indicate that the LWI sensor relay is in the 'wet' mode.

a. If the pen arm does respond, release the switch and carefully reset the tension-adjustor knob to its original position.

b. If the pen arm does not respond, trouble-shoot as follows:

(1) Check the wiring and all electrical connections between the sensor relay, unijunction assembly, and the LWI pen arm relay.

(2) Check the charge on the battery. It must be higher than 9 V.

(3) Check the gap on the LWI pen arm relay. It may be necessary to reduce the gap by turning the gap adjustment screw *clockwise.*

3. Trouble-shooting the unijunction assembly.
   a. If (1) and (2) have been completed and the pen arm is still not functioning or is responding only slightly, the fault may lie in the unijunction assembly. The malfunction is most likely due to an improperly functioning unijunction transistor. This transistor is sensitive to very high temperatures, such as temperatures encountered when soldering.
   b. Replace the unijunction transistor, being careful not to overheat during soldering. If trouble persists, proceed as follows using a simple voltmeter.
      (1) Make sure the voltmeter is adjusted to read DC volts.
      (2) Push and hold the unijunction accelerator button. This activates the 4.7k ohm resistor.
         (a) Place the positive probe of the voltmeter on the positive end of the capacitor (a, Fig. 17).
         (b) Place the negative probe of the voltmeter on the negative end of the capacitor (b, Fig. 17).
         (c) The voltage should increase to about 8.5 V, discharge, increase again to 8.5 V, and discharge again in a cyclic fashion, with each cycle lasting several seconds.
      (3) The circuitry may be checked without activating the unijunction accelerator switch.
         (a) Place the positive probe of the voltmeter on the junction of the 200 ohm and 470k ohm resistors (c, Fig. 17).
         (b) Place the negative probe on the positive end (a, Fig. 17) of the capacitor and observe the ohm scale on the voltmeter.
         (c) Cycling should also be observed on the ohm scale if the negative probe is kept on the capcitor while the positive probe is moved to the 220 ohm resistor (d, Fig. 17).
         (d) If cycling is not observed, check for loose wiring and cold solder joints or replace resistors.

Testing the Wetness-sensing Element for Its Response to Wetting and Drying

The sensing element should be 'conditioned' before it is attached to the sensor housing, but this does not insure that it is going to function properly. Thus, it should be tested for its response

to wetting and drying before it is calibrated. Proceed as follows:

1. Press the sensor indicator switch.
   a. If the LED glows, proceed to (2).
   b. If the LED does not glow, loosen the tension-adjustor bolt and slowly turn the knob clockwise until the LED glows. Now proceed to (2).
2. Loosen and turn the tension adjustor knob *counterclockwise* slowly until the LED stops glowing, then release the sensor indicator switch.
3. Spray the wetness sensing element evenly with a fine mist until it is thoroughly wetted.
4. Press the sensor indicator switch.
   a. The LED should be glowing within a few minutes after the element has been wetted, indicating that the element has responded to wetting. If the LED is glowing, release the switch and proceed to (5).
   b. If the LED fails to glow after several minutes, the fault is with the sensing element. Either 'recondition' the element or attach another 'conditioned' element. If the elements continue to fail to respond, another type of cotton line or perhaps degreased hemp will be necessary. Once the proper element has been found, proceed to (5).
5. Allow the sensing element to dry, then push the sensor indicator switch.
   a. The LED should not glow, indicating that the sensing element has returned to its original tension. Proceed to (6).
   b. If the LED continues to glow, then the element has not responded properly to drying. Either the element needs further 'conditioning' or, if that fails, another type of line is necessary. Once the proper element has been found, proceed to (6).
6. If the element has responded properly to wetting and drying, turn the tension-adjustor knob *counterclockwise* to further ease the tension on the sensing element. Repeat STEPS 1-5. Repeat several times until you find the limits of the sensing element's capacity to respond to wetting and drying. This should help in deciding the level of sensitivity (response to condensation and precipitation) that can be expected.

NOTE: This testing procedure should be performed periodically (perhaps once a month) to make sure the element is continuing to respond properly.

Calibrating the Leaf Wetness Indicator

The sensing apparatus must be adjusted so that the leaf wetness indicator will be activated only during the time interval when leaf

surfaces are observed to be wet. Leaf wetness may be due to condensation (dew) or precipitation (rain), and the sensing apparatus can be adjusted to record only during periods of precipitation on leaf surfaces or to record periods of condensation in addition to precipitation. The degree of sensitivity required, of course, will be determined by the type of data that must be recorded. Calibration is accomplished by altering the tension of the sensing element. Calibration can be achieved through actual observations of rainfall or 'artificially' by spraying water on the sensing element and foliage.

Calibrating for precipitation.

Rainfall procedure. In the rainfall procedure, tension of the element is adjusted when a given amount of rain (such as 0.25 mm) is recorded by the digital rain gauge. Before the designated amount of rain has fallen, press the sensor indicator switch. The LED should *not* glow. If it does, turn the sensing element tension adjustment knob counterclockwise until the LED stops glowing. When the designated amount of rain has fallen, turn the tension-adjustor knob *clockwise* slowly until the light glows, indicating that the sensor has made electrical contact and the unijunction assembly and LWI pen arm relay are activated. The sensor is now calibrated to detect the beginning of a precipitation period.

The sensor should be checked throughout the wet period to make sure that electrical contact is maintained until the plant parts are dry. This is done by pushing the sensor-indicator switch and checking the LED to make sure it is glowing. If it isn't glowing, turn the tension-adjustor knob *clockwise* until it does glow. The precipitation period ends when the foliage or other plant parts are considered dry, and this may be determined visually or through touch, i.e. running your hand along the plant and checking the palm for moisture. At the time it is determined that the leaves are dry, the LED should not glow when the switch is pressed. The sensor is now calibrated to detect the end of a wetting period initiated by precipitation.

It is recommended that the LWI be checked the next few times precipitation occurs to make sure the sensor is functioning properly, adjusting tension on the sensing element when necessary so that the trace on the chart corresponds to actual periods of leaf wetting.

Artificial wetting procedure. During dry weather, calibration can be achieved by using an atomizer to thoroughly wet the sensing element and parts of the plant and then adjusting tension on the sensing element to correspond to the wetting and drying time of the plant parts. This procedure may not be as accurate as the rainfall procedure, so the sensor should also be checked during periods of actual precipitation and adjustments made when necessary. This procedure is useful, however, when establishing the instrument in

the field during dry weather, or when checking the performance of the sensing element during dry weather.

Calibrating for condensation.

It is possible to 'fine tune' the sensing element so that it will respond to condensation in addition to precipitation. If this degree of sensitivity to moisture is desired, the procedure to follow is similar to the calibration procedure for precipitation described above except that observations for condensation on the foliage, rather than precipitation, must be made.

Wiring the Digital Rain Gauge and Rain-intensity Pen Arm Relay

Materials

(1) Digital rain gauge (Edmund Scientific Co., Barrington, New Jersey 08007; catalog # 72,319). The rain gauge includes one tipping bucket and rain collector for 0.25 mm measurements, one digital counter, and two battery clips.
(2) 9V batteries
(4) wire connectors
(1) roll of electrical tape
(1) roll of 18 gauge wire

Instructions (refer to Fig. 18)

1. The tipping bucket comes wired with a length of two-conductor speaker wire. Loosen the screw on the side of the digital counter housing and insert the end of the wire through the hole below the screw.
2. Slit the end of the speaker wire to separate the copper and silver strands for about 10 cm.
3. Strip about 1 cm of insulation from each battery clip wire and snap the clips onto the 9V batteries.
4. Connect the two positive leads from the batteries to the copper wire coming from the tipping bucket (a), and solder and cover with a wire connector.
5. Solder the two lengths of 18 gauge wire to the prongs on the 12V rain-intensity relay attached to the plexiglass stage in the hygrothermograph. Cut the wires about 60 cm (long enough to extend from the hygrothermograph to the digital counter).
   a. Insert the wires through the drilled holes in the upper stage plate and the hygrothermograph base plate.
   b. Connect one wire to the negative lead of one of the batteries (b), then solder and cover with a wire connector.

c. Connect the second wire to the silver wire extending from the digital counter and to one of the black wires connected to the counter (c).

6. Connect the remaining black wire from the digital counter to the remaining negative lead of the 9V battery (d), then solder and cover with a wire connector.
7. Squeeze the sides of the digital counter plastic housing and insert wires and batteries. Cover the base of the counter with electrical tape to secure the batteries and wires in the counter housing.

Operational Check of the Digital Rain Gauge and Rain-intensity Relay and Trouble-shooting

1. Manually rock the tipping bucket from side to side. Each time the bucket tips, the digital counter should advance one digit and the rain-intensity pen arm should respond with a 'clicking' sound as the pen arm moves downward and returns immediately to its original position.
2. If either event fails to occur, trouble-shoot as follows:
   a. Check the tipping bucket to make sure the magnetic bead is close enough to the magneswitch to connect the metal strips as the bead swings by. You should hear a 'clicking' sound when the metal strips make contact.
   b. Check all wiring to make sure all parts are wired correctly and all connections are secure.
   c. Test the 9V batteries to make sure they are fully charged.
   d. Check the pen arm to make sure it is not pressed too tightly against the drum.
   e. Check the gap on the rain-intensity pen arm relay. It may be necessary to reduce the gap by turning the gap adjustment screw *clockwise.*

Calibrating the Digital Rain Gauge (refer to Fig. 3)

The digital rain gauge is calibrated at the factory to within 5.0% accuracy, but it is advisable to check the instrument periodically to insure that it is calibrated to record each 0.25 mm of rain. Proceed as follows:

1. Remove the collector, making sure that the tipping bucket assembly is on a *level* surface.
2. Turn the two "B" adjusting screws *clockwise* one turn or to seat (whichever comes first).
3. Rock the tipping bucket from side to side to make sure it is free and settles solidly on the upright or on screw "B" on each side. The tipping bucket must not 'float' upward after hitting screw "B".

NOTE: During all calibrating, make sure the tipping bucket leg and magnetic bead are against the end of adjusting screw "A".

4. If the tipping bucket 'floats', turn adjusting screw "A" *clockwise* (work in ¼ turns or less) while holding the locking nut behind it.
5. When the tipping bucket action is correct, carefully add 10 cc of water to the tipping bucket. This much water should make the bucket tip. Try for two trips, one each way, with a total of 20 cc of water.
   a. If more than 20 cc of water is required, turn adjusting screw "A" *counterclockwise.*
   b. If less than 20 cc of water is required, turn adjusting screw "A" *clockwise* while holding the locking nut.
   c. After each try, check for 'float'.
6. After achieving two trips with 20 cc of water, turn adjusting screws "B" until each side requires 10 cc of water. When this is achieved and the bucket does not 'float' after tipping, the instrument is calibrated to register each 0.25 mm of rainwater.
7. Make one final check to make sure the tipping bucket leg and magnetic bead are against adjusting screw "A" and you can hear a clicking sound when the bucket is tipping.

NOTE: The collector should be washed periodically with a mild detergent to insure that the collector surface is clean and the orifice is clear of debris so that the rainwater will run freely from the collector surface to the tipping bucket. It is also advisable to clean the bucket occasionally to insure accuracy of the measurements.

CONSTRUCTING THE 3-PEN ARM DESIGN

The constructions and wiring of the 3-pen arm and 4-pen arm designs are similar in most respects. Refer to the construction of the 4-pen arm design for constructing, wiring, and calibrating the LWI apparatus and the digital rain gauge apparatus.

Constructing the Plexiglass Mount

Materials

(1) plexiglass sheet, 4.5 cm wide, 15 cm long, and 6 mm thick
(2) bolts, 2 cm long
(1) SPDT momentary spring-return switch

Instructions (refer to Fig. 19)

A) Measure 5 cm from one end of the plexiglass sheet and draw a line perpendicular to the end.

B) Heat the plexiglass carefully with a flame or heat strip until the plexiglass becomes flexible.
C) Bend the plexiglass to form a 90 degree angle; cool to harden in position.
D) Drill 3 holes in a triangle-pattern in the 5 cm end.
E) Position the plexiglass on the metal upright plate of the hygrothermograph, 1.5 cm from the top and 2 cm from the front edge.
F) Drill and tap three holes in the upright plate to correspond with the 3 holes in the plexiglass.

NOTE: If the model pictured is used, a 1.5 x 3.0 cm hole must be cut in the plexiglass mount to clear the temperature-sensing apparatus before attaching the mount to the upright.

G) Drill a 6 mm hole 4 cm from the 5 cm mark and 2 cm from the back edge of the plexiglass mount; then attach the Unijunction Accelerator Switch. (See Fig. 20)
H) Drill a 4 mm hole 7 cm from the 5 cm mark and 5 cm from the front edge of the plexiglass mount; then attach the rain-intensity 12V relay and pen arm. (See pp. 8-12 for constructing the relay and pen arm.)
I) Drill two 4 mm holes in the back edge of the plexiglass mount and two corresponding 4 mm holes in the circuit board. The holes will be used later to attach the circuit board to the plexiglass mount.
J) Drill a 6 mm hole in the hygrothermograph base similar to the hole drilled for the 4-pen arm design (see p. 9). This hole allows wires to be passed through the hygrothermograph base.
K) Mount the plexiglass onto the hygrothermograph upright.

Mounting the 12 V Solenoid to the Hygrothermograph Upright

Materials

(1) T6X12-C-12VDC pull-type solenoid, duty cycle continuous (Guardian Electric Mfg. Co., Chicago, Illinois)
(2) spacers, 2.54 cm long
(2) 30 cm long bolts, and 4 nuts

Instructions (refer to Fig. 20)

A) File flat the end of the humidity adjustment rod to a width of 2 mm to allow the rod to fit into the groove of the solenoid shaft. Insert a pin through the shaft and rod to fasten the assembly.

B) Push the two bolts through the solenoid bracket.
   1) Thread each bolt with a nut, spacer, and then another nut.
   2) Drill and tap two 3 mm holes 1.3 cm to each side of the humidity adjustment rod and bolt the solenoid into place.

Correcting the Response of the Humidity-adjustment Arm

Materials

(1) finely-wound spring
(2) bolts, 1.5 cm long

Instructions (refer to Fig. 20)

The standard spring on the humidity adjustment arm of the hygrothermograph is too stiff to allow the solenoid shaft to retract and record on the hygrothermograph chart. For this reason, a finely-wound spring must be mounted on the arm.

A) Remove the standard spring attached to the humidity-adjusting arm.
B) Drill and tap a 3 mm hole in the humidity adjusting arm just above the securing pin of the old spring.
C) Drill and tap another 3 mm hole in the hygrothermograph base in a direct line with the hole drilled in the adjusting arm.
D) Use the two 1.5 cm long bolts to secure the spring from the hygrothermograph base to the back of the humidity adjusting arm. The installation of this spring allows a greater flexibility in the adjustment of the humidity and tension on the solenoid shaft.

Wiring the Solenoid Unijunction Assembly and Unijunction Accelerator Switch

Materials

(1) 330 ohm resistor, ½ watt, 5% tolerance
(1) unijunction transistor
(1) 123AP transistor
(1) 220 ohm resistor, ½ watt, 5% tolerance
(1) 470 ohm resistor, ½ watt, 5% tolerance
(1) circuit board
(1) 500uf 0-25DC electrolytic capacitor
(1) 4.7k ohm resistor, ½ watt, 5% tolerance
(1) spool of 18 gauge stranded single-conductor wire

Instructions (refer to Fig. 21)

A) Assemble the electronic components comprising the unijunction assembly on the circuit board and solder into place.

B) Two wires should be extending from the solenoid.
   1) Solder one wire to the junction of the 220 ohm and 470k ohm resistors.
   2) Solder the other wire to the collector on the transistor.
C) Wire the unijunction accelerator switch as explained on pp. 15-16.

Attaching a Spore Trap to the Instrumentation

Materials

(1) length of two-conductor wire
(4) 'quick-disconnect' wire connectors

Instructions

It may be desirable to attach to the leaf wetness indicator a spore trap or other device that will be activated only during periods of leaf wetness. This can be accomplished very simply *when the sensor relay is being wired.* The sensor relay has 4 pairs of prongs. One member of the 2nd and 3rd pair have already been wired (see 'Wiring the Relay', p. 11). To attach a spore trap, wire the other member of each pair by repeating step 3 under 'Wiring the Relay.'

1. Attach 'quick-disconnect' wire connectors to the ends of the copper and silver strands of each speaker wire lead that is extending through the PVC 'T'. One lead will be attached to the spore trap and one lead to a battery. The leads should be labeled so they will not be confused with other leads extending through the PVC 'T'.
2. Cut two lengths of two-conductor wire that will extend from the sensor to the spore trap when it is positioned in the field.
   a. Attach 'quick-disconnect' connectors to the strands at one end of each wire. They will connect to the leads extending from the PVC 'T'.
   b. The leads at the other end of the wires will be attached to the spore trap and the battery.

NOTE: If a spore trap is to be used, it may be necessary to include an additional battery to meet the power requirements of the spore trap.

FIGURE LEGENDS

FIG. 1. Recording of environmental variables by the A) 4-pen arm and B) 3-pen arm hygrothermographs.

FIG. 2. Major components of the field instrumentation: rain collector (a_1); digital counter (a_2); leaf wetness indicator (b); hygrothermograph (c).

FIG. 3. Diagram of tipping-bucket assembly of the digital rain gauge. Cutaway view showing magnet (a); magneswitch (b); adjusting screws "B", and adjusting screw "A".

FIG. 4. Leaf wetness indicator with cutaway view of the LWI sensor relay: wetness sensing element (a); sensor relay (b); sensing element tension-adjustor (c); LWI housing (d); light emitting diode (LED) (e); sensor-indicator switch (f).

FIG. 5. Diagram of sensor relay in the A) "dry" position and B) "wet" position: contact plate (C_p); copper contact (C_1); attachment for sensing element (a).

FIG. 6. Schematic representation of the 4-pen arm unijunction assembly circuitry: $R_1 = 220\Omega$; $R_2 = 470k\Omega$; $R_3 = 4.7k\Omega$; $C_1 =$ 500 UF; T_1 = ECG6 401; K_1 = 12 VDC relay.

FIG. 7. Steps in preparation of the LWI and rain-intensity pen arm relays. (Letters refer to steps explained in text)

FIG. 8. Steps in construction of the LWI and rain-intensity pen arms and attachment to the pen arm relay. (Letters refer to steps explained in text)

FIG. 9. Diagram of location of the plexiglass base on the 4-pen arm hygrothermograph.

FIG. 10. Diagram of dimensions for constructing the plexiglass stage for 4-pen arm design.

FIG. 11. Completed plexiglass stage with pen arm relays attached.

FIG. 12. Sensor relay with wire (a) attached to the contact plate and a slit (b) cut in the cover.

FIG. 13. Steps required in seating the sensor relay into the test cap and in fashioning and installing a hook onto the wire extending from the sensor relay: hook for sensor attachment and wire to bind hook to relay (a); hook bound in position (b); slits cut in PVC test cap (c).

FIG. 14. Wiring diagram for the sensor relay and the sensor-indicator assembly.

FIG. 15. Construction of the sensor PVC housing and the cotton wetness-sensing element.

FIG. 16. Rear-view of 4-pen arm hygrothermograph showing attachment of the unijunction accelerator switch (a) and the unijunction circuit board (b).

FIG. 17. Close-up of unijunction components on the circuit board: positive end of capacitor (a); 470 kΩ resistor (b); junction of the 220 Ω and 470 kΩ resistors (c); 220 Ω resistor (d); T_1 transistor (e).

FIG. 18. Wiring diagram of the digital rain gauge and rain-intensity pen arm relay.

FIG. 19. Attachment of the plexiglass mount and unijunction accelerator switch for the 3-pen arm hygrothermograph.

FIG. 20. Rear-view of the 3-pen arm hygrothermograph showing attachment of the pull-type solenoid, spacer, and spring.

FIG. 21. Schematic representation of the electrical circuitry for the 3-pen arm solenoid unijunction assembly and unijunction accelerator switch.

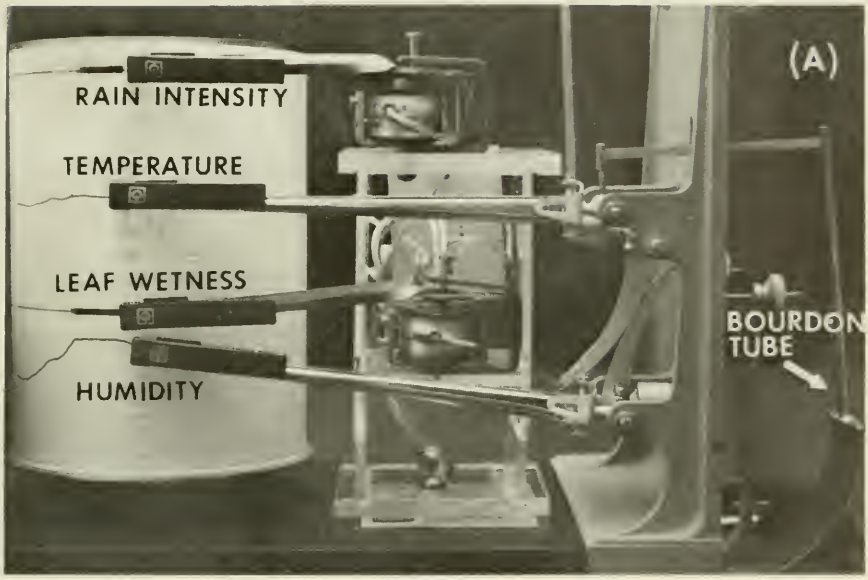
RAIN INTENSITY
TEMPERATURE
LEAF WETNESS
HUMIDITY
(A)
BOURDON
TUBE

FIG. 1A

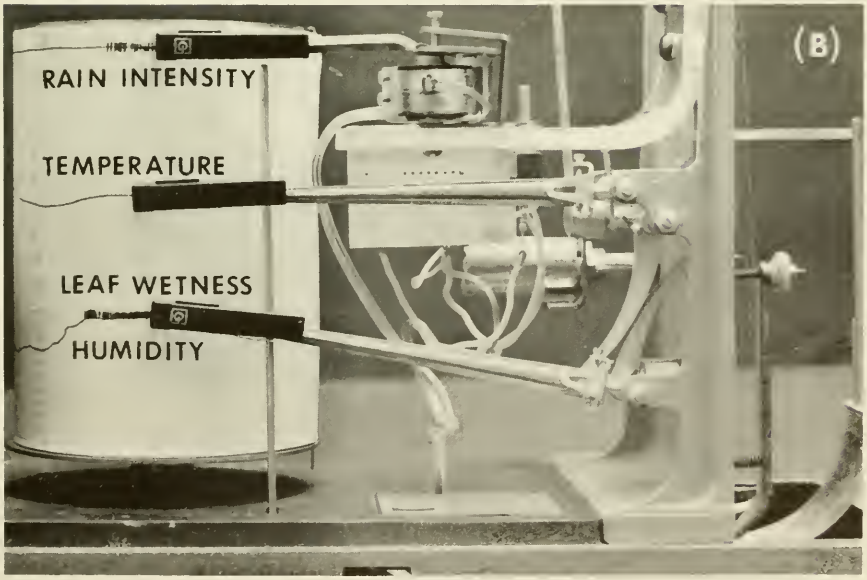
RAIN INTENSITY
TEMPERATURE
LEAF WETNESS
HUMIDITY
(B)

FIG. 1B

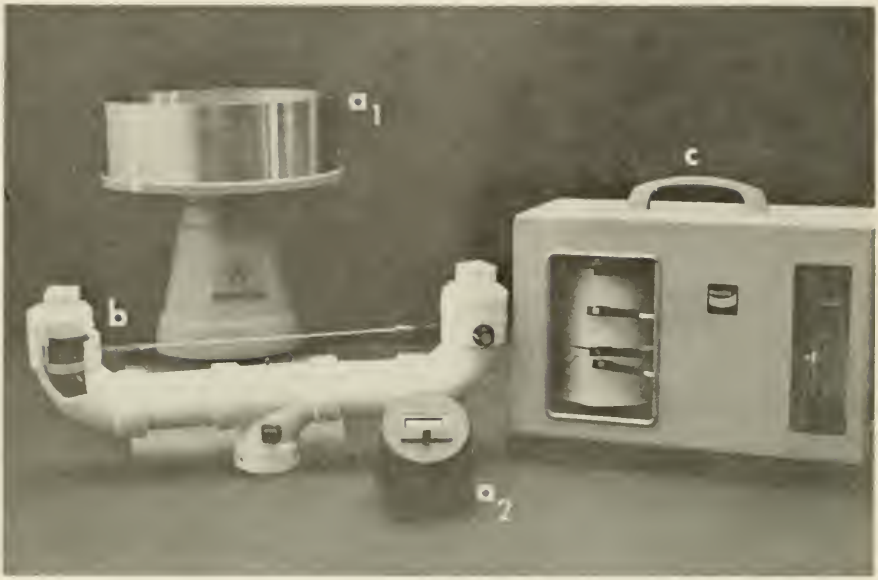

FIG. 2

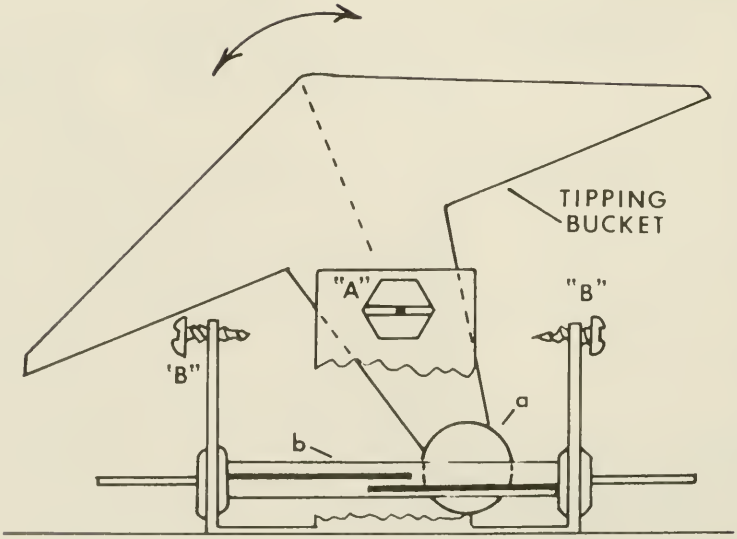

FIG. 3

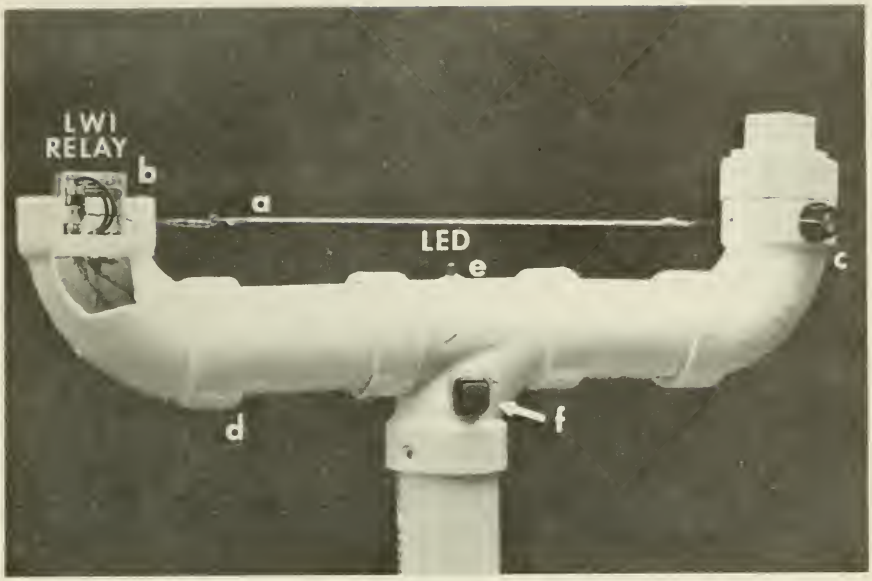
LWI
RELAY
b
a
LED
e
c
d
f

FIG. 4

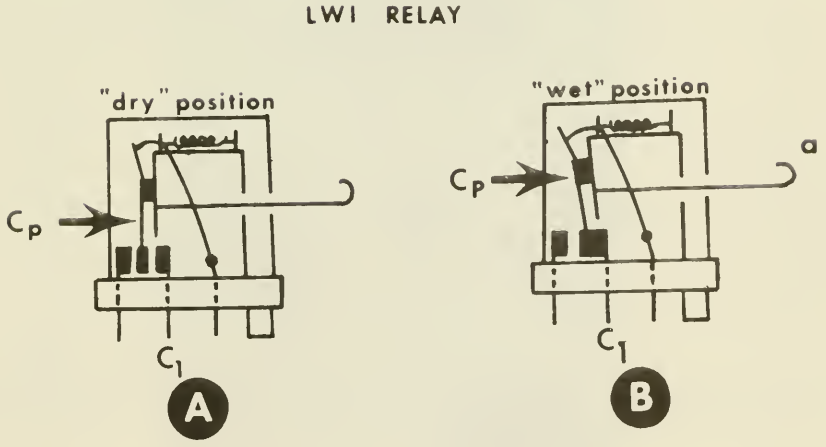
LWI RELAY
"dry" position
Cp
C1
A
"wet" position
Cp
a
C1
B

FIG. 5

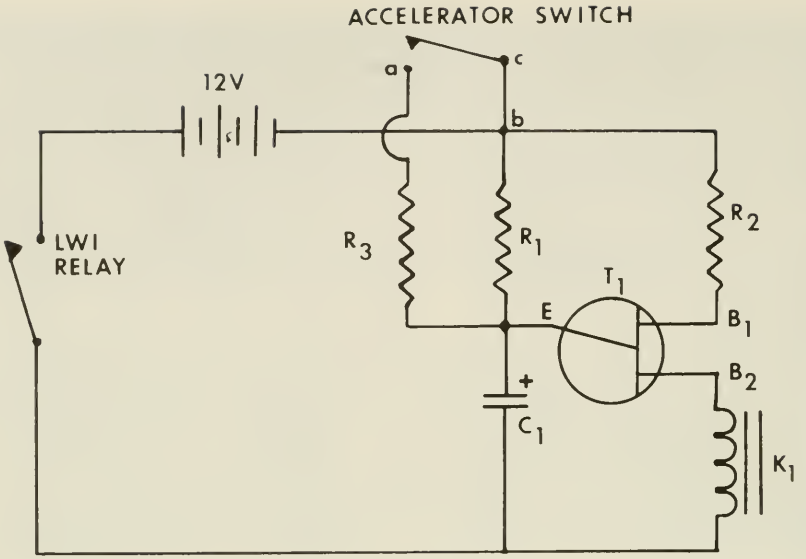
ACCELERATOR SWITCH
12V
a
c
b
LWI
RELAY
R3
R1
R2
T1
E
B1
B2
+
C1
K1

FIG. 6

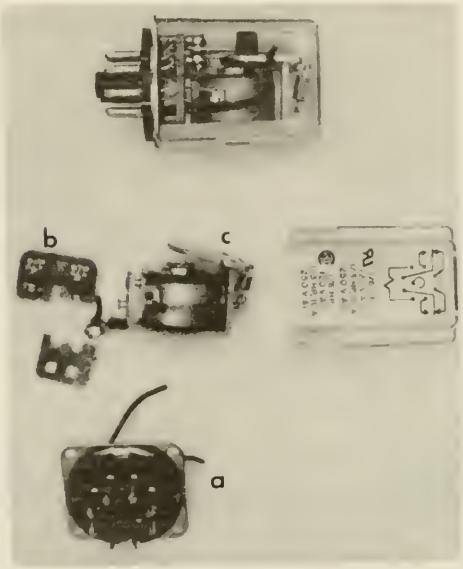
b
c
a

FIG. 7

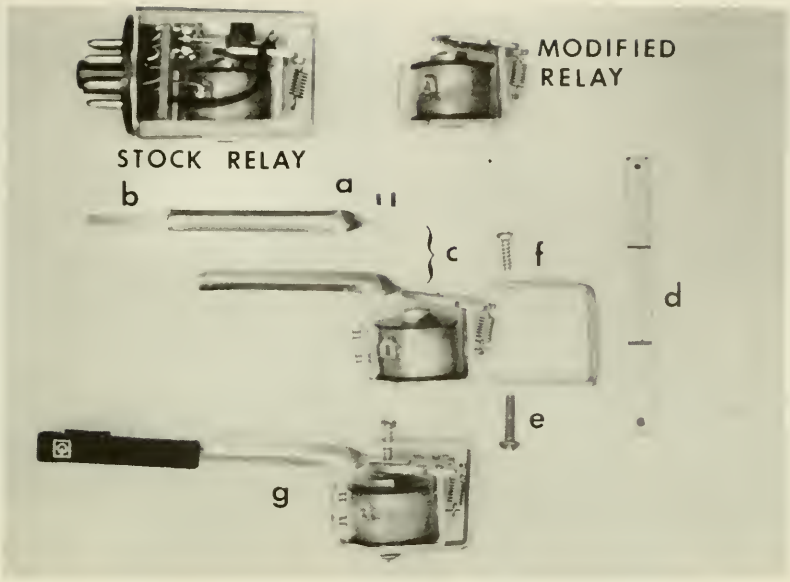
MODIFIED
RELAY
STOCK RELAY
a
b
c
d
e
f
g

FIG. 8

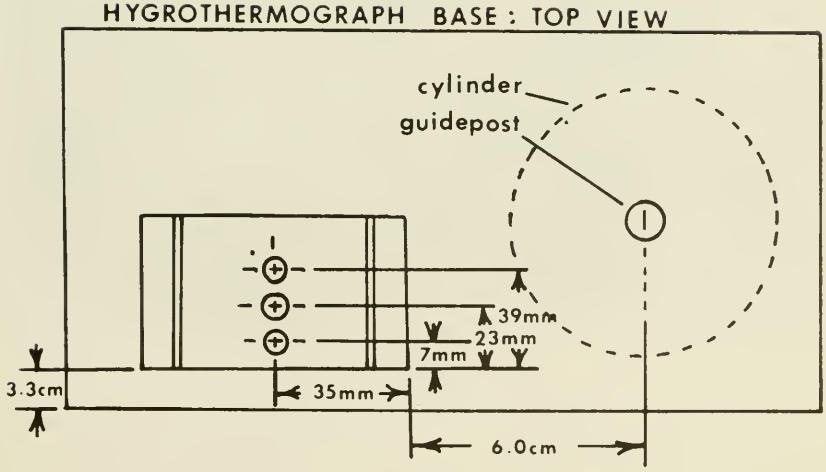
HYGROTHERMOGRAPH BASE : TOP VIEW
cylinder
guidepost
39mm
23mm
7mm
3.3cm
35mm
6.0cm

FIG. 9

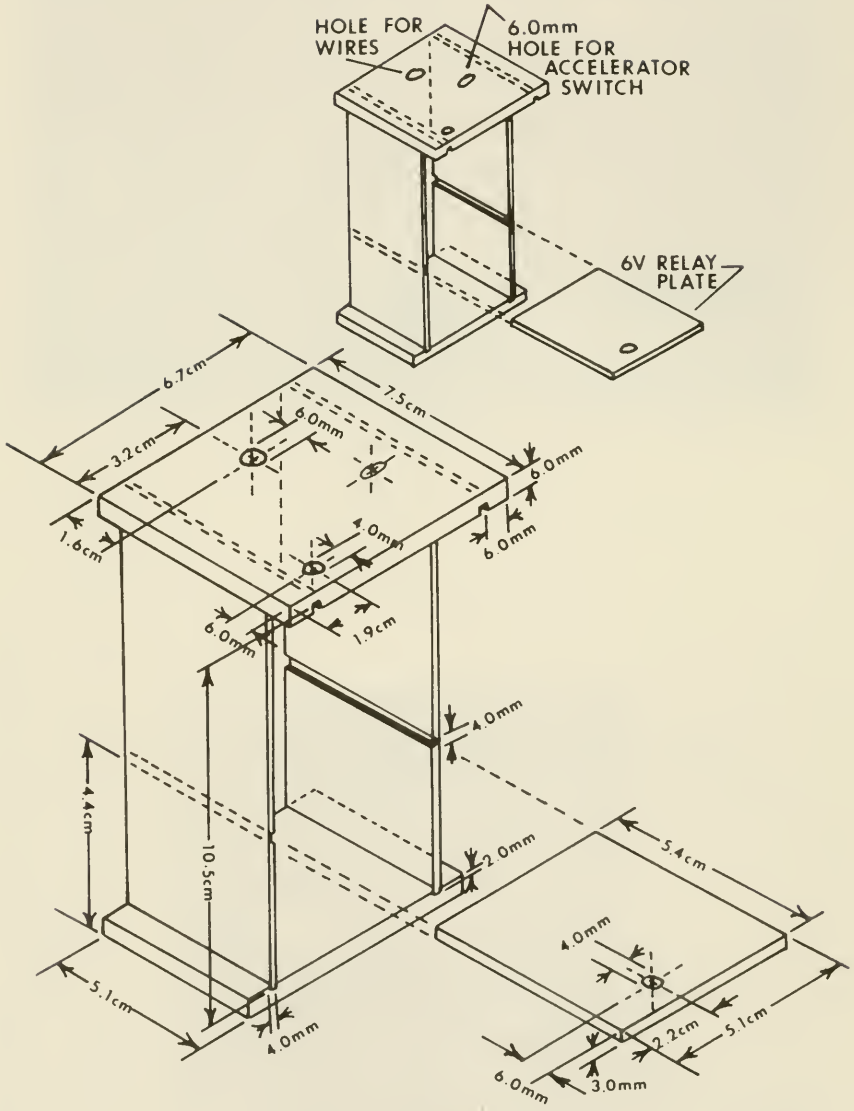
HOLE FOR WIRES
6.0mm
HOLE FOR ACCELERATOR SWITCH
6V RELAY PLATE
6.7cm
7.5cm
3.2cm
6.0mm
6.0mm
1.6cm
4.0mm
6.0mm
6.0mm
1.9cm
4.0mm
4.4cm
10.5cm
2.0mm
5.4cm
4.0mm
5.1cm
4.0mm
2.2cm
5.1cm
6.0mm
3.0mm

FIG. 10

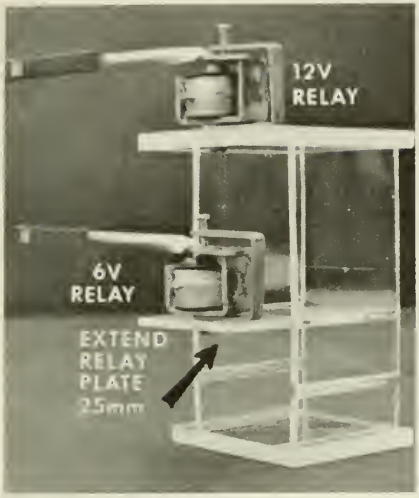

FIG. 11

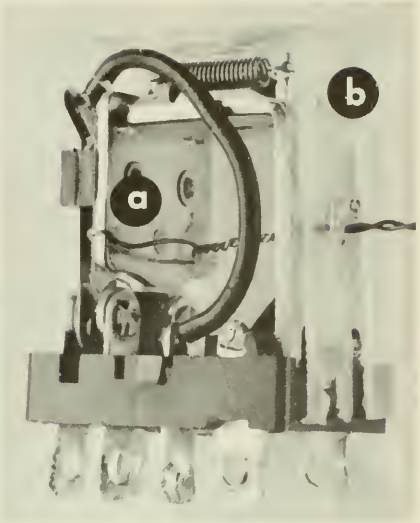

FIG. 12

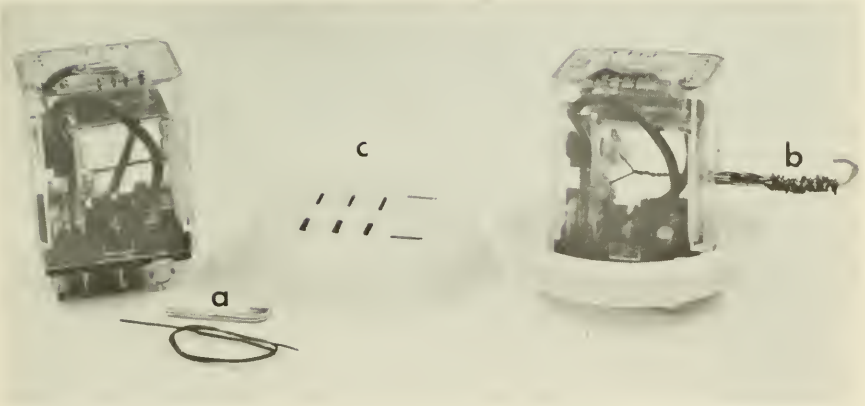

FIG. 13

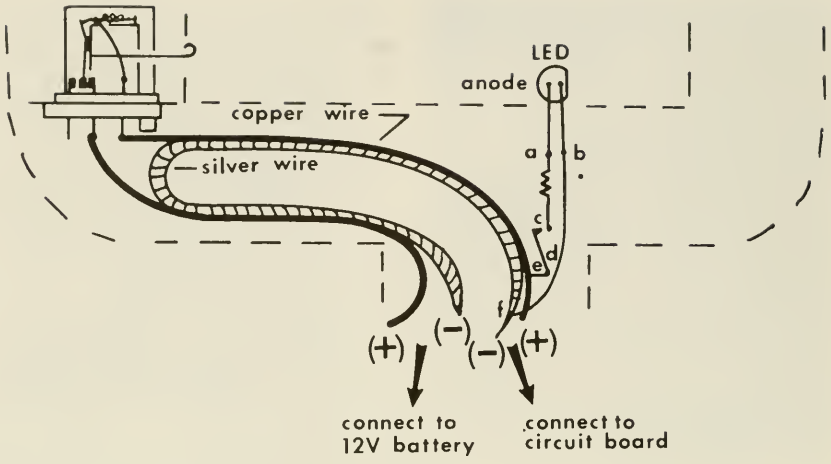
LED
anode
copper wire
silver wire
a
b
c
d
e
f
(+)
(−)
(−)
(+)
connect to
12V battery
connect to
circuit board

FIG. 14

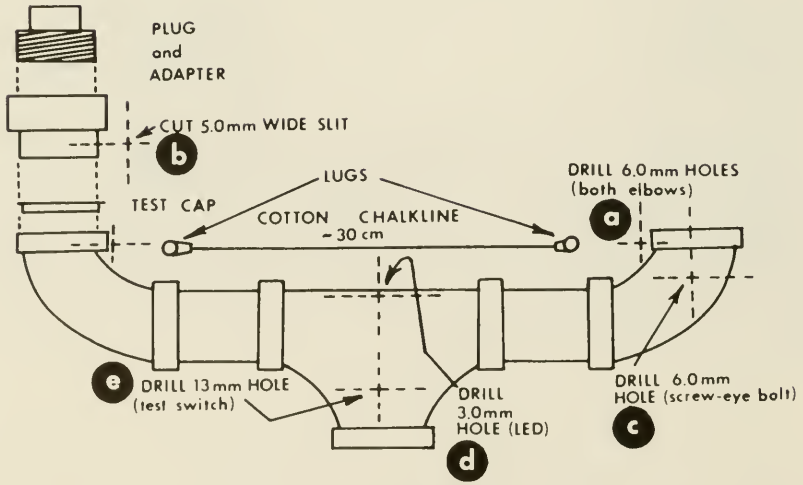
PLUG
and
ADAPTER
CUT 5.0mm WIDE SLIT
b
LUGS
TEST CAP
COTTON CHALKLINE
– 30 cm
DRILL 6.0mm HOLES
(both elbows)
a
e
DRILL 13mm HOLE
(test switch)
DRILL
3.0mm
HOLE (LED)
d
DRILL 6.0mm
HOLE (screw-eye bolt)
c

FIG. 15

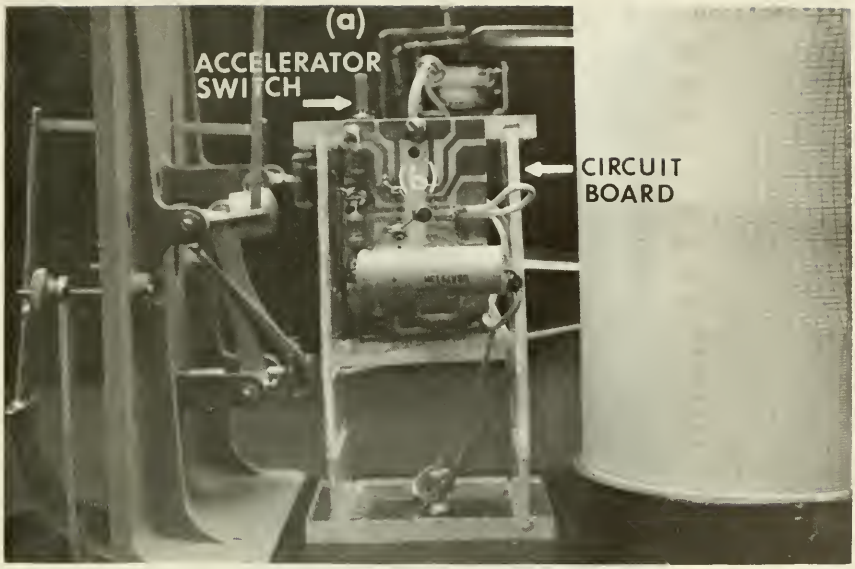
(a)
ACCELERATOR
SWITCH
CIRCUIT
BOARD

FIG. 16

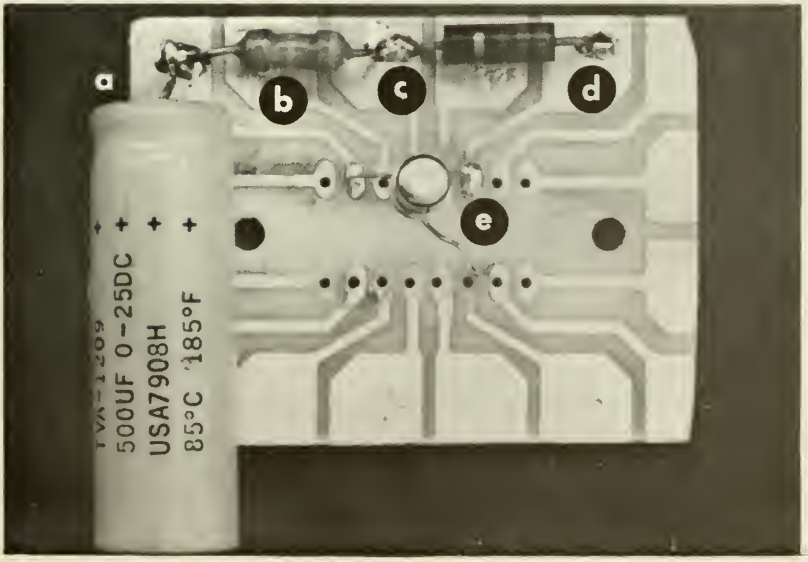
a
b
c
d
e
500UF 0-25DC
USA7908H
85°C 185°F

FIG. 17

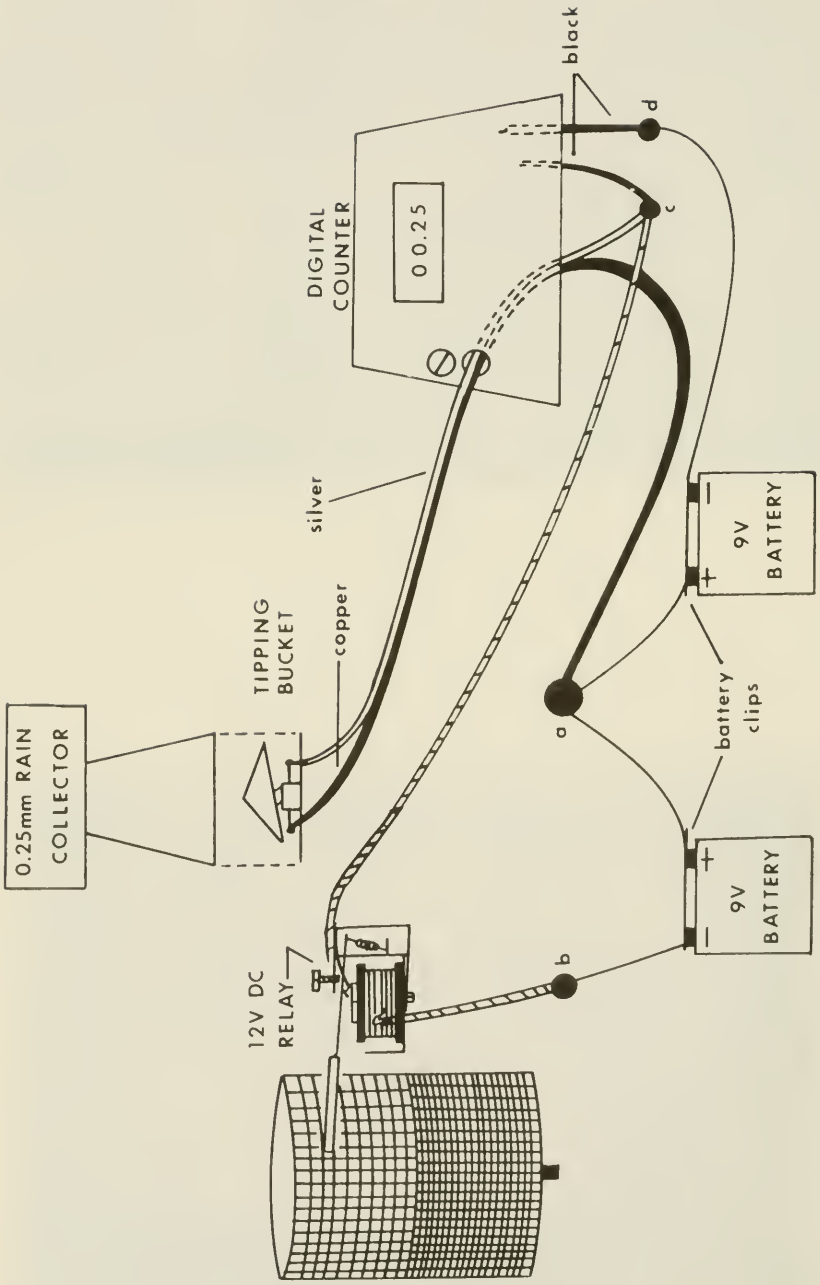
0.25mm RAIN COLLECTOR
TIPPING BUCKET
copper
silver
DIGITAL COUNTER
00.25
black
d
c
9V BATTERY
battery clips
a
9V BATTERY
12V DC RELAY
b

FIG. 18

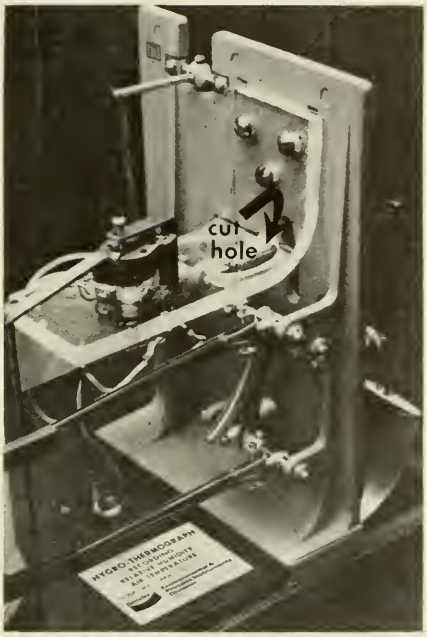
cut
hole
HYGRO-THERMOGRAPH

FIG. 19

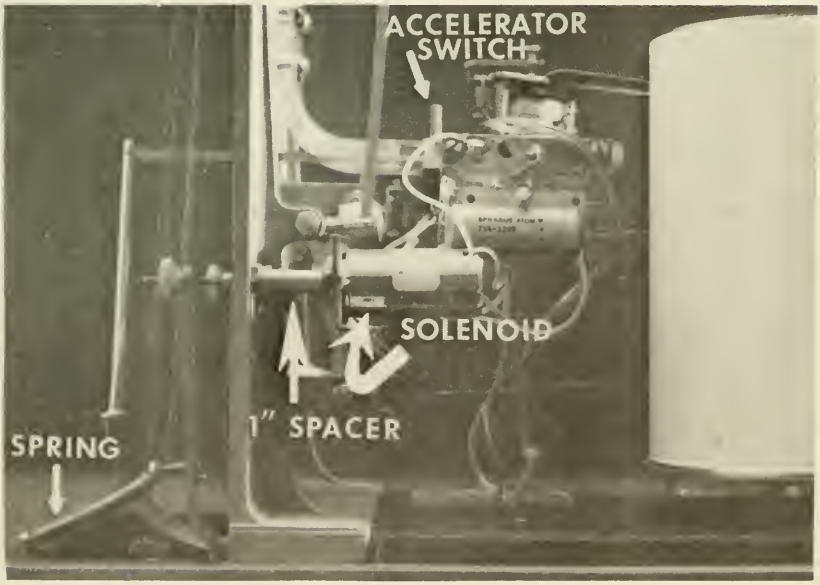
ACCELERATOR
SWITCH
SOLENOID
1" SPACER
SPRING

FIG. 20

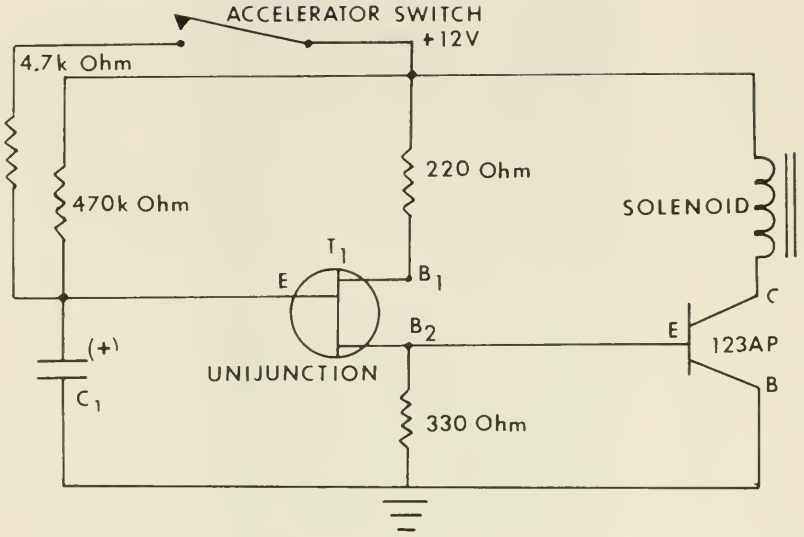
ACCELERATOR SWITCH
+12V
4.7k Ohm
220 Ohm
470k Ohm
SOLENOID
T1
E
B1
C
B2
E
123AP
(+)
UNIJUNCTION
B
C1
330 Ohm

FIG. 21